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A proposition in design education with a potential in commercial venture in small aircraft manufacture

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Abstract

Critical reviews made by various organisations on both sides of the Atlantic have identified the need for continuing changes in engineering teaching curriculum, emphasising inclusion of more intense design education to meet the requirements of industry. The concept of this paper outlines introducing design education within aerospace engineering in an integrated approach involving industries, universities, regional technical colleges and vocational institutes to produce a marketable ab initio trainer aircraft. The task involves conceptual studies, design, analysis and testing of the aircraft through course assignments. The aircraft is to be certified and manufactured by a participating industry also responsible for product liability. By combining the educational programmmes of university students and industrial apprentices, the bulk of manpower can be obtained free with quality of workmanship sufficient for prototyping (preproduction aircraft) assured through strict supervision by experienced personnel from both academia and industry. An innovative management set-up, modelled as a 'Virtual Company', is proposed as an organisational structure to execute the project. The success of the proposition depends primarily on planning and co-ordination of the project. The crux of the progress hinges on the availability of hi-tech resources from industry and attitude changes in the teaching establishments. The benefits are the output from institutes who have acquired the analytical capabilities and trade skills along with the opportunities to acquire those traits of creative synthesis and judgement required by the industry, while producing a marketable product with no development cost to be amortised in the selling price (more than 15% price reduction possible).

Keywords: Design education; Small aircraft; Manufacture; Virtual company

Abbreviation: CE – concurrent engineering; DBT – design built team; CFD – computational fluid dynamics; FEM – finite element methods; CAD – computer-aided design; CAM – computer-aided manufacture; TQM – total quality management; REC – Regional Engineering College; ATS - Apprentice Training School; QUB - Queen's University of Belfast; HND - Higher National Diploma (UK); ABET - Accreditation Board for Engineering & Tech (US)

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1. Introduction

To meet industry's needs, a freshly graduated engineer must have a short conversion time to be productive in line with the specialist task assigned to him. He must have a good grasp in the mathematics and engineering sciences necessary for analysis, and enough experience for decision making. He must be capable of working under minimal supervision and must have creative synthesis which comes from experience that academia finds difficult to offer. Industrial environment will require new recruits to work in a team in appreciation of time, cost and quality under TQM, quite different from class room experience.

Traditionally, universities offer fundamentals of the theories on engineering subjects to develop analytical abilities. The courses are structured with all material available in text books/notes. The problem assignments are straightforward having unique answers. This may be termed as 'closed-form' education. Closed-form problems are easy to grade and the teacher's knowledge is not challenged (relatively).

On the other hand, the new trends in industries require tackling 'open-form' problems where in a real world environment there is no single answer. The best solution is to be decided through inter-disciplinary interaction of concurrent engineering within Design Built Teams, where Total Quality Management is needed to bring out 'customer driven' products at the best value for money. Offering open ended courses in design education, covering industrial requirements, is more difficult and could challenge academic for not having the industrial experience. The associative features of 'close' and 'open' form education are given diagramatically in Fig. 1.

The roles of scientists and engineers are defined (Von Karman – 'A scientist discovers that which exists. An engineer creates that which never was'). LaGraff [2] in his paper compared US aerospace education with systems in three European and two Asiatic countries. The advanced countries recognised the difference between engineer and scientist with appropriate career recognition (engineers getting better remuneration/position – some are with Ph.D.). The need for design education at an early stage in undergraduate studies emerged as a paramount necessity. The academic curriculum revision in the USA and the UK have gradually introduced typical projects/courses having components of 'real-life' experience by involving 'mentors' (experienced engineers) from industries.

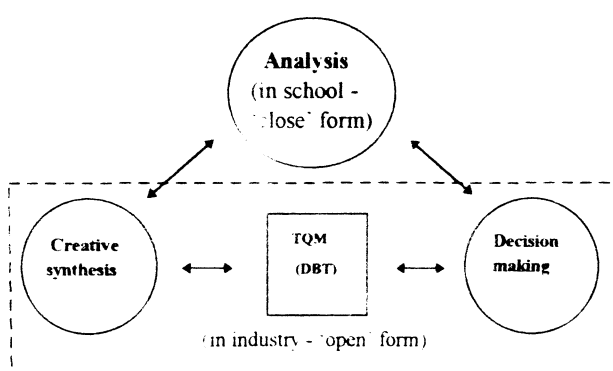


Fig. 1. (modified from Nicolai [1]).

The project proposal given in this paper is to embody the 'real-life' engineering design experience in an educational curriculum through course work and industrial collaboration, resulting in a viable end product (aircraft description given in Ref. [3]) to compete in free market as a business venture. It satisfies both commercial and academic interests by earning revenue for sustenance and assisting students to become better engineers in a creative environment. Building aircraft in universities is nothing new, but so far they lacked a commercial approach. This paper suggests aircraft design education with a business plan involving commercial partners in an innovative management set-up of a 'Virtual Company' (see later). The proposal is presently under study by the Department of Aeronautical Engineering at the QUB and by the interested local industries.

The concept is simple but may prove difficult to implement as it defines new organisational boundaries with no reference model to benefit from. There could be initial lack of appreciation as it requires culture changes within participating organisations.

2. Background

Since the surprise launch of 'Sputnik' in the 1950s, the US academic institution continuously reviewed their aerospace engineering teaching curriculum to remain competitive. Since the mid-1980s, in the changing scenario of globalised free market economy, there has been increasing demand for freshly trained personnel with ability to be productive and adapt fast, in the fast track of changes, to satisfy commercial interests of industries competing with each other, nationally and internationally. Of late in the early 1990s, the consequences of post-cold-war thaw demanded another fresh look. The peace dividend resulted in shrinking activities in Aerospace Engineering with all around financial cut backs and job losses (especially in defence and space sector) – an environment not favourable for academia. The immediate future in educational institutes faces the inevitable migration of resources, both men and material, to other growing areas. Therefore, aeronautical teaching requires a careful evaluation with more diverse content in curriculum that would retain, if not expand, academic interest to help and encourage industry as a commercial partner.

Extensive survey/reviews have been made by various US bodies with wide range of recommendations, all stressing the need to incorporate more intense design education in curriculum. Various models of curriculum planning exist in different universities.

A 1989 survey of aerospace engineering programs at US universities is given by Yechout [4]. It summarises that the curricula are being squeezed by conflicting demands for added requirements, greater flexibility and mastery of basics. It brought out the struggle to gain recognition of design's importance in the academic curriculum. It stressed the need for strong co-operative relationship with industry to meet the challenges of the changing world. Further survey was conducted in 1995 by Walker et al [5] of University of Cincinnati to determine the views of industrial, governmental and academia on the required contents of future aerospace curricula. Williams et al. [6] give the ABET review to ensure quality in US schools by teaching engineering design.

Nicolai [1] described the 'closed' and 'open' form teachings. His comments reflected the consensus of industry:– (US) engineering schools are producing great scientists but mediocre engineers. Ladesic [7] witnessed loss of US leadership in many fields of technology, stemming primarily from decline in the capabilities of aerospace engineering graduates, who are well prepared to appreciate the elegance of theory but lacked in design skills vital to generate national economy. He recommended that the US engineering schools must do a better job of preparing students for solving real world problems they will encounter in industry.

In a powerful paper, McMasters [8] of Boeing Company discussed the need for enhanced design education in engineering curricula in the US. He observed that there exists a gap between the real world of industry and academic world of university. In general, many colleges exhibit complacence, with academia seeking recognition through publication and the industry became 'dissatisfied customers' by using their main product, the fresh graduates. McMaster et al. [9] also gave a status report on Boeing's three months on-the-job activities to improve fresh graduate recruitment process and provide the students with a realistic view of engineering practices in industry.

Frederick et al. [10] gave the effective use of mentors from American Rocket Company and NASA offering 'Design of Thermal System' at the senior level of University of Alabama. Wells et al. [11] described a three-year programme (starting 1992) in Rotorcraft design (not building) by Arizona State University with NASA grant and support by McDonnell Douglas Helicopter System. At both the cases, the effort resulted in high degree of motivation felt by the students by the stimulation offered by the mentors from industry. Wilczynski et al. [12] gave another example of industry–university–high school partnership functioning as a composite unit. The conclusion of the paper affirmed the need for such partnership.

Roskam [13] of University of Kansas saw crisis in aircraft design education in spite of adequate course work on basic technologies (e.g. aerodynamics, structure, propulsion etc.). He mentioned the consensus among executives in aircraft industry that large number of US schools give their student insufficient knowledge of aircraft design as an integrated system. In his other paper [14] he outlined what should be taught. Lamancusa [15] described a new approach taken into the engineering curriculum, in collaboration between three universities (Penn State, Puerto Rico University and University of Washington) and industry partnership, to teach integrated design and manufacturing, not necessarily confined to aerospace engineering. Separate physical facilities were earmarked as 'Learning Factory' to teach new courses specifically geared to cater for industrial needs. Covert [16] gave a sample course-work for study, which is in line with other papers. Bergey et al [17] from University of Oklahoma also stated crisis in undergraduate aerospace design education, in line with what Roskam, McMasters and others have found. They suggested changes in universities to recognise the creative role of aerospace design in education.

In the UK, changes have taken place in a quieter manner. As early as in the early 1960s, the Fielden Report [18] stressed the role of teaching design in Universities. In 1976, Moulton [19] outlined the need for engineering design education. Doyle et al [20] have outlined a three-year undergraduate curriculum at Durham University, UK, with design project (not confined to aerospace) in an engineering degree course. Simmons [21], also from Durham University, gave an account of dependence on local industries to make available experienced mentors. Cranfield University, UK, has established a Department of Vehicle Design within the College of Aeronautics. The need for fresh graduates to have industrial exposure was also felt locally in Belfast area. Since 1994, QUB implemented final year undergraduate course work with assigned industrial project in collaboration with Bombardier Aerospace-Short to give students with real life work experience (more details given in the next section).

3. QUB — shorts project

This paper benefits from the experiences gained from undergraduate projects carried out by the Queen's University of Belfast in collaboration with Bombardier Aerospace-Short, Belfast, on industrial problems concerning aircraft currently in production. Research collaboration between QUB and Shorts has been successfully carried out for some time with well-developed inter-personnel relationship. The long standing relationship and experiences serve as the foundation of this paper.

For the last few years, final year students of the Aeronautical Engineering Department at QUB have undertaken team-based project studies with Bombardier Aerospace-Short, Belfast. Each student team was required to examine a complex 'real' aerospace product involving all aspects of aeronautical engineering including production considerations. Although these studies were purely academic in nature, valuable practical experience was gathered to set up working relationship for progress.

Cross, an ex-student of QUB, is now employed by Shorts. Her report [22], as the team leader of the project carried out in the academic year of 1994–1995, identified benefits including attaining the skills of team working, communication, timeliness in completing assignments, cost appreciation, ability to comprise open-form problems and take decision in DBT. This exposure was not available in routine class room work and helped her to be productive in short time after she joined the company. The experiences gained by the students of 1995–1996 and 1996–1997 batches were the same as Cross's.

In the early 1990s, the first author of this paper, then an engineer at Bombardier Aerospace-Shorts, helped the apprentices at the ATS to construct two demonstration wind tunnels, proving that the quality of workmanship is adequate for prototype aircraft building.

4. The proposed organisational model — the virtual company

To administrate the proposed project in an efficient manner, an innovative organisational set-up as a 'Virtual Company [23]' is described. [The word 'virtual' may not be interpreted in the sense of computer terminology of simulating non-existing set-ups in Visual Display Units.]

A virtual manufacturing company consists of a number of custom-fit independent organisations geographically dispersed but managed as a composite unit, although the sub-units may be under separate management. Virtual company exists for the particular project and gets dissolved when the task is completed. The composition of the Virtual Company for this paper is shown below.

The Master Company has a lean set-up with no overheads and minimum manpower of a Chief Engineer responsible for design, certification and product liability, a Managing Director to administrate business and minimal supporting staff as required, operating from a small office. The

Master Company takes full shape when production starts after the 'Virtual Company' is dissolved on completion of prototype aircraft building and certification. In the initial manufacturing phase, it may operate as a mere assembly shop from components made through subcontracting Partner Company. The leanness of the Master Company could keep it agile and flexible to respond fast to unforeseen hold-ups at least cost.

Virtual Company

(Chief engineer and at least one representative from each of the participating sub-unit listed below) a semi-autonomous system within academic schedule

(1)	(2)	(3)	(4)	(5)
Master Company (Primary Industrial Partner)	**Partner Company** (Secondary Industrial Partner)	**Universities**	**Vocational Institutes** (ATS)	**Regional technical colleges** (REC)
Chief Engineer	Experienced Mentors	Faculty	Instructors	Teachers
Certification + Product Liability + Manufacture	Hi-Tech resources CAD + CFD + FEM etc	Design/Test through formal course work (CFD/FEM)	Prototype build through formal course work (mock-up)	Design support & Build/test through formal course work

The Partner Company is large company, the power house supplying hi-tech resources by redeploying existing resources for a product not in conflict competition with their own. The Partner Company is not in a benevolent role but deeply entrenched to benefit from the project. It benefits from recruiting superior fresh engineering graduates to become productive in considerably shorter period resulting in appreciable savings in expensive conversion time and also attracts future business partnership with the Master Company in a seamless sharing of task obligations. As a large company affecting the region, its role in the socio-techno-economic contribution will have major influence in their own business.

5. The methodology

The novelty of this paper is to propose a methodology, which will demonstrate that embedding a commercial interest in an academic curriculum is possible. A breakdown of task content and resource requirement are outlined that will not violate academic schedule. The time frame involved is likely to be around 50% longer than had it been pursued in industry alone, but the analytical contents would cover larger territories of creative synthesis.

The Virtual Company forms a few months ahead of the beginning of the academic session (September in general) to prepare class room time-table in-line with the academic requirements. The student interest cannot be diluted as their future is the main business of this project. Any inadvertent slide in progress needs to be made up during vacation period.

Table 1
Manpower availability

Organisation	Class	Number of human resource	Remarks
Student apprentice			
University	Level 2	30	Pre-final year
University	Level 3	30	Bachelor's degree
University	Level 4	6 to 8	Masters degree
2 × RECs	Final year	80	All departments
ATS	Final year	50	All departments
Instructors			
University	Faculty	5 + 2	Aeronautical + mechanical
University	Technician	2	Aeronautical
2 × REC	Teacher	10	Aeronautical + others
ATS	Instructor	6	Shop floor practise
Partner Company	Mentor	7	Part time basis
Master Company	Chief Engineer	1	Full time
Total (minimum estimate – in average 10% more):			
Student apprentice		200 approximately	(Not working full time)
Instructors		23	(Not all working full time)

A four year time frame is aimed to complete the project (an outline of the Programme Schedule, in phases of development, is given in Section 9). It involves level 2, level 3 (Bachelor's Degree) and level 4 (Master's Degree) of a four year course in aeronautical engineering at the university. On graduation at the end of an academic year, the continuing students stays with the project with fresh input at level 2. However, because of high quality requirement of practical skill for construction and testing, only the final year vocational students (HNDs/apprentices) are engaged for three years in succession, each year starting with a fresh batch.

Minimum (approximate) student/apprentice and instructor/mentor manpower availability is shown in Table 1.

Therefore, the quantity of free of cost man power available is more than adequate. Considering a full time effort of this kind carried out in industry, it requires less than 20 engineers and craftsmen working for about 2.5 years to certify (JAR-VLA) the aircraft. A total manpower of more than 220 for this project spanning for 4 years (say working one day a week in class room plus home assignment contents) is more than adequate.

The quality need not be underestimated as the students and apprentices are only months away from joining industry. Much will depend on the level of supervision and dedication given by the experienced mentors from industry, the highly qualified faculty members at university and the seasoned teachers/instructors, many of them having once served in industry. Belfast area has well equipped RECs, one of them offers aeronautical engineering courses with emphasis on practical aspects such as maintenance, operation and production considerations. Shorts ATS is an award winning establishment. In their assigned tasks, students and apprentices have already demonstrated quality adequate for designing and building a small general aviation aircraft using a proven but up-to-date technology level.

The class room work starts from the recommendations of market studies already carried out, laying the guidelines for the aircraft specification requirements. The market study procedures are lengthy and expensive with field work. Since it has little academic content, it is not included in the curriculum but will be explained to all students, in the form of a seminar at the beginning of the course work, introducing the project and expectations.

The Chief Engineer, from the Master Company, is responsible for the design and certification carried out through DBT, which consists of one experienced member of each of the participating sub-units forming the Virtual Company. The Chief Engineer must be a person who has designed similar aircraft in the past and possesses multi-disciplinary experiences both as an engineer in industry and as a faculty member in university. The progress of the project is tied down to academic schedules and, therefore, should be monitored by the teachers/instructors from the respective institutes. The members of the Virtual Company meet every week to assess progress and administrative matters. Separate technical meetings, in regular intervals, are to be carried out in concurrent engineering environment involving the students from all participating sub-units.

High-technology transfer from a large Partner Company is essential to the project. Approximately seven experienced engineers (not all working simultaneously or full time) from Partner Company are required. These engineers, serving as mentors, are the technology drivers and the institute teachers, with much higher degrees, may have to become learning instructors in the Project. Considerable culture change may be required by both the industry and the academic circles. At least, one mentor is required in each of the following disciplines: (1) aerodynamics, (2) structures and materials (3) mechanical systems e.g. power plant, controls, etc. (4) electrical/avionics system, (5) Testing, (6) CAD and (7) manufacturing (CAM). These are the experienced engineers who are willing to offer their expertise for the cause in return for some form of recognition/award.

The manufacturing considerations are an integral part of the project. After certification, at the closure of the Virtual Company, the jigs and tools used for the preproduction aircraft are to be converted into hard tooling for seamless continuation of production by the Master Company. The Department of Mechanical Engineering and/or other universities with requisite specialisation may join the project with well defined task assignments in manufacturing considerations. Design and certification details generated by the Teaching/Training establishments are to be transferred to the Master Company, who would act as the design authority for the product, oversee future growth, support and liabilities.

The critical designs, tooling concepts and testing are performed at universities. The less complex designs, manufacturing details and testing are conducted at the Regional Engineering Colleges. Construction of one set of prototype (pre-production) aircraft and one set of test specimen are taken up by Apprentice Training School. Sponsorship of outside agencies to build one-off specialised components (e.g. Canopy, undercarriage etc.) is encouraged and may be followed up as business partners when production starts. Engine, instruments etc are bought-out items. Flight tests are to be carried out by hiring qualified test pilot, possibly at places like Cranfield or taken up by the hi-tech Partner Company on payment. 60 sorties are planned for JAR-VLA certification.

Project cost frame of the programme is below one million US Dollars. More than 90% of the total development goes as man-hour cost, which is free through this methodology. The rest is involved with material/hardware purchase and testing. The engine for prototype certification can be obtained free on loan. Man-hour cost of mentors at university can be partly recovered from government grants as trainer-on-job and the rest is invested in kindness for their own benefit. The Master Company is to provide funds of the order of $100,000 spread over four year period. Much of this can be shared by local Government grants and/or through sponsorship by other interested industries with a potential to become eventual supplier when production begins. Details of costing is left out as proprietary information.

6. The product (3-view diagram not given)

The product chosen is in a low-cost development area where a market exists in general aviation under JAR-VLA certification. The task obligation of this project is to design and construct a prototype (pre-production)/test specimens of a two-place ab initio club trainer/recreational flying aircraft, offered both as fly-away and home-built kit form. The design uses conventional proven technology, with primary design objectives of safety, comfort and economy without overlooking aircraft performance. The design and analysis employ the latest methods of CFD, FEM and CAD/CAM.

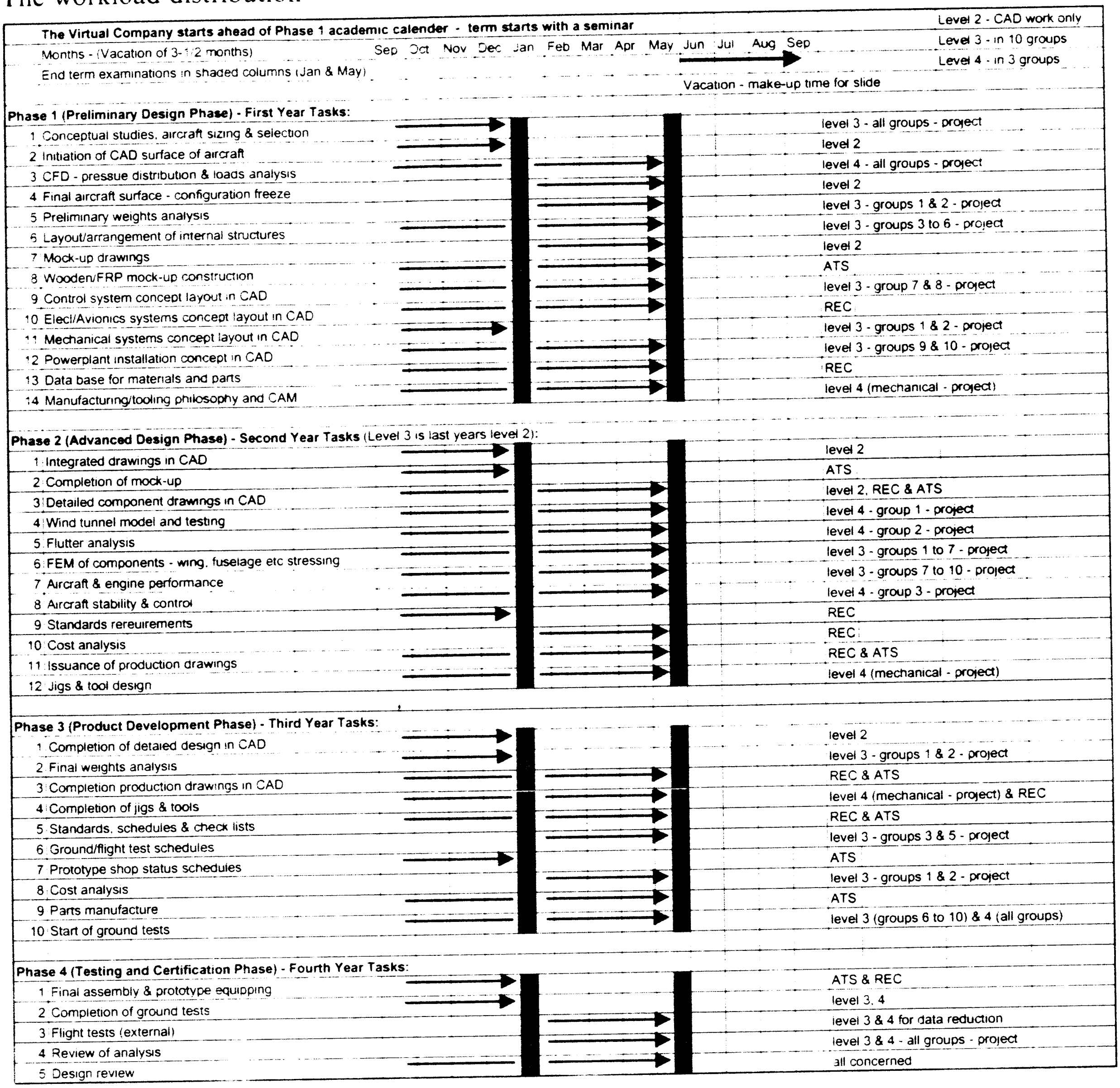
Ref. [3] gives detailed description of the product as an all metal low-wing aircraft to be built in modular construction with growth potential in a family of variants up to four-place utility aircraft to be certified under FAR 23 category. The manufacturing and tooling philosophy of the modular concept of design is an integral part of the project so that production can start immediately after the certification is completed.

The baseline model has maximum take-off weight less than 600 kg, powered by 80 HP liquid-cooled piston engine capable of operating with AVGAS or MOGAS. Its maximum speed at mid-operational weight is estimated to be around 120 knots and stalling speed around 40 knots with full flaps. It is stressed to $+4g$ to $-2g$ (a variant at $+6g$ to $-3g$). The wing area is $9.3\,m^2$ ($100\,ft^2$).

7. Work load/programme schedule

To demonstrate the concept of this paper, the Gantt chart (see Chart 1) gives work load distribution in a simplistic manner. The programme schedule is outlined in four distinct phases, each one year in duration in line with academic calender. Level 3 is divided into 10 groups of 3 students each and level 4 is divided into 3 groups of 2 students each to tackle distinct breakdown of task assignments from the overall classification given in the Gantt chart. Level 2 is engaged in CAD drawings only. It is to be noted that the Virtual Company is to be formed several months ahead of the term to prepare schedule and details of group assignments, in line with academic time table. Close monitoring of progress is essential through weekly meetings. Any slide needs to be made up in vacation periods. (Details of deliverables at the end of each Phases are given in Ref. [3]).

Chart 1
The workload distribution



8. Discussion

Background review clearly emphasises the tendency amongst the academics to gain recognition through publication and attracting grant for research. Not enough effort has been given to teach design education catering for industry needs that generate national fund to support research.

Partnership between university and industry is essential for national growth. It appears that there is no standard method to ensure high-quality design education in university curriculum.

Top degrees are not producing top designers for national growth. There should be a culture change within the society to recognise the needs of the nation. An extreme example of a country with one of the world's largest pool of Ph.D.s, but burdened with traditional culture and lack of accountability of scientists, exhibits trend of scientists migrate to lucrative senior engineering design posts without design experience. It has resulted in under performance and become heavily dependent on 'foreign assistance'.

Various recommendations have been made, almost all indicating a need for change of culture in the university to attract experienced engineers from industry to offer 'open-form' courses in design education. One of the biggest impediment to the implementation of the project will be the complacence in university. The faculty with higher degrees have little incentive to become learning instructures of the 'open-form' courses given by the engineers from industry. University administration can come to the rescue by recognising creative design at par with the elegance of theory. The power of combining theory and appliction is desirable to any society.

Change of attitude is also needed by the industry to join the 'Virtual Company'. This would be a fine example of industry's investment in people. Industry should be prepared to free their best engineers for a short while. This paper implies that some form of recognition/award could be given to the mentors from industry. It could be sabbatical leave for a few years to gain higher degrees in design. It could be in any other form of reward (including financial) satisfactory to the engineer concerned. This also gives the opportunity to groom the succession chain and possibly retain enabling expertise, if redundancy looms.

The other major impediment is the Partner Company's willingness to proceed with a scheme, having no reference model with which to gauge possible benefits to their Company. The concept of sparing top engineers for few years in return of their advancement/reward may escape the theme of 'investing in people'. This should not deter them from taking a positive step where potential for benefit outweighs loss. The positive outcome of recruiting more mature graduates and contributing to the socio-techno-economic infrastructure of the region can not be ignored.

The goal of this purposeful project focuses in bringing teaching institutes and universities as business partners with broader impact on regional growth by simultaneous output of better qualified engineers/technicians as well as a finished product that need not only be small aircraft but can be any suitable complex hi-tech product. The increased complexity of aerospace engineering in multi-disciplinary environment and rapid growth of technology makes aircraft building a good candidate for design education in universities.

9. Conclusion

By substantiation of student/apprentice capability and providing details regarding experienced mentors/teachers and low funding outlay for a conventional design, this paper demonstrates that the concept is feasible. This unique proposal fills the gap between teaching institutes and industry.

Free trained manpower, under strict experienced supervision, should eleminate amortisation of design cost in the selling price, giving a competitive advantage of a value-added product, in the free market. Planning and coordination for execution would be vital for the project success.

Although the proposal is presently under evaluation by interested industries and university, it is reasonable to assume initial lack of appreciation by some even when there is a general support in the community. The major impediment arises from the inertial effects, which hinder change to a new, untried organisational boundary without a reference model. Unless the need is vital, there is a tendency to resist a change of culture.

The main impediment to implementation would be the complacence in university and a cautious approach by Partner Company to release (even for brief period) top engineers for their own gain which is not adding immediately to the share holders' interest. With some form of incentives, these barriers can be broken. University has nothing to lose by recognising the importance of design at par with research but it will require administrative changes to formulate recognition. With some restructuring, the large Partner Company should be able to redeploy human resource, especially, if there is slack period.

To reinforce the concept of this innovative set-up of a Virtual Company, it needs to be evaluted beyond interested partners to obtain back-up support coming from administrative offices (government, societies, national co-ordination bodies to promote business etc) for the regional development. Some kind of ad hoc grant (an example in Ref. [11]) needs to be worked out. The proposed model has never been tried anywhere. The suggestion may be considered as a method and not a solution.

The favourable impact on the region's socio-techno-economic infrastructure can be increased from the lessons learned from this project. The willingness of both teaching establishments and industries will result in a better qualified next generation who would advance the cause of the business growth, offering employment opportunities for the students involved in other projects carried out in similar lines.

In today's World, the first author of this paper considers that the recognition of engineers should be no less than that of scientists. Instead of counting the number of papers published, the new yardstick should be a measure of the resources generated for the nation. There should be more accountability for the type of work carried out by engineers and scientists. Clarence 'Kelly' Johnson did not get a Noble prize – there should be an equivalent award for top designers/engineers.

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